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Towards an industrial manufactured morphing trailing edge flap system for wind turbines

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Abstract

A flap actuation system, the Controllable Rubber Trailing Edge Flap (CRTEF), for distributed load control on a wind turbine blade has been developed in the period from 2006 to 2010 at DTU. The function of the system and its capability to change the lift on a blade section was measured during a wind tunnel experiment in 2009 with promising results. This led in 2011 to initiation of a new research project INDUFLAP with the main aim to transfer the flap technology to industry as concerns manufacturing and testing. Three industrial partners are participating in the project. Rehau (DE) and Dansk Gummi Industri (DK) work on flap manufacturing and Hydratech Industries (DK) is developing the powering system for the flaps and the control system. DTU is the coordinator of the project. Flap prototypes have been manufactured in a continuous thermoplastic extrusion process and a unique rotating test rig has been developed and build, based on a 100kW turbine platform. A 2m (span) x 1m (chord) blade section with the flap system is mounted at the end of a 10m long boom rotated up to 50-60 rpm. Measurements comprise surface pressure measurements for detailed monitoring of the flap actions.

Introduction

Several numerical studies [1] in the past 10 years have shown big potentials for load reduction on MW turbines using distributed control for alleviation of the fluctuating loads along the blade span. However, the requirements by the wind turbine industry of robust actuator solutions where the strongest specifications mean no metal and electrical parts in the blades have so far limited the use of the smart blade technology on wind turbines.

The numerical and experimental analyses in the past have mostly been focusing on trailing edge flaps as the distributed control concept. Although small scale blade and rotor experiments [2], [3] in wind tunnels have been conducted in the past these concepts are not considered to be directly up-scalable for modern large scale wind turbine blades, without any additional mechanical amplification parts.

The lack of technology solutions for flap control on MW wind turbines initiated back in 2006 a development work at Risø (now DTU Wind Energy) with the main objective to develop a robust

and efficient flap system for implementation on MW scale turbines. In the present paper this development work is summarized but with main focus on the recent activities of transferring the technology to industry as concerns manufacturing methods and testing. This work is carried out within the 3½ years project INDUFLAP (2011-2024), funded by the Danish Energy Agency through the EUDP 2011 programme. The industrial project partners in the project are Rehau (DE), Hydratech Industries (DK) and Dansk Gummi Industri (DK). DTU is coordinator of the project.

Flap actuation concept

The initial investigations back in 2006 of finding a suitable, robust flap actuation concept led to the design of the Controllable Rubber Trailing Edge Flap (CRTEF). A design concept that fulfills the requirements of: 1) no mechanical parts; 2) no metal parts and 3) no electronics in the blade. The CRTEF is a trailing edge flap manufactured in an elastic material such as e.g. rubber or a polymer material and with suitable reinforced voids that can be pressurized with a medium such as air or a liquid and, thus giving the desired deflection of the flap. If the lower row of voids are pressurized the

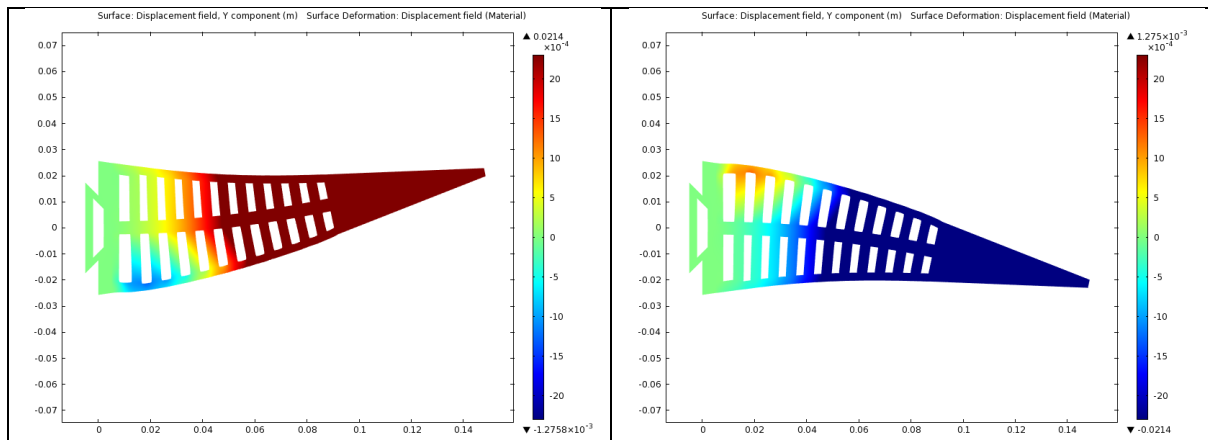


Figure 1 To the left, the lower row of voids are pressurized giving an upward deflection and to the right the upper row of voids are pressurized giving a downward deflection.

flap will deflect upwards as shown in the left illustration of Figure 1 and likewise a downward deflection is obtained by pressurizing the upper row of voids.

The development work from 2006 to 2010

In this period several different flap prototypes were designed and manufactured as described in [4]. Two basically different concepts were investigated: 1) flaps with voids in the chordwise direction as shown in the left part of Figure 2, and 2) flap designs with voids in the spanwise direction as shown to the right in Figure 2. The flap designs with the chordwise voids were used in the first part of the development work from 2006 to 2010. Prototypes with a dimension of 15cm in chordwise length and 30cm in spanwise length were manufactured in different materials, e.g. silicone and with different reinforcements of the voids [4]. A major milestone was achieved in 2009 where the flap concept was tested on a 1.9m long (spanwise) and 1m (chordwise) blade section in the Velux open jet wind tunnel in Denmark [4]. A maximum change of C_l of about 0.2 was achieved with the prototype flap and the time constant of the actuation was determined to about 0.1s using a pneumatic pressurizing system of the voids [4].

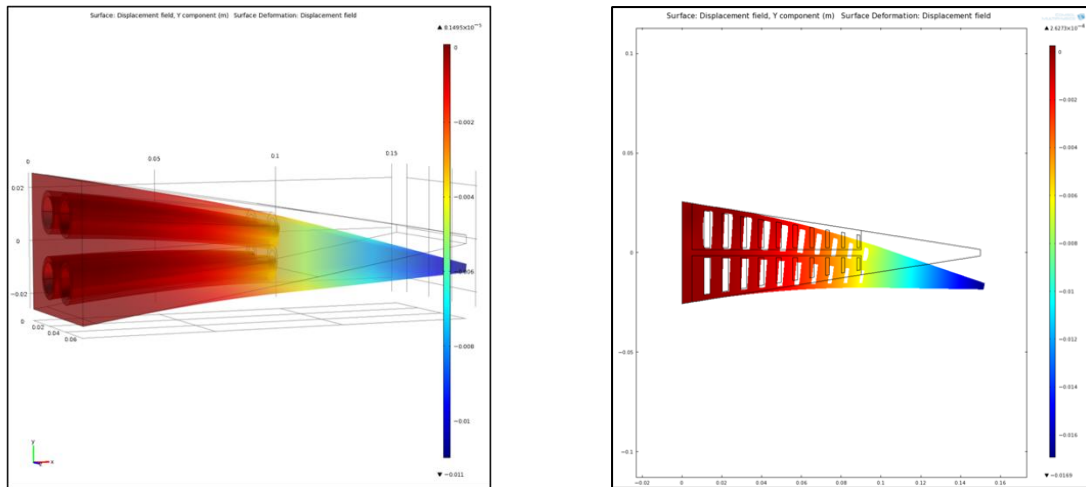


Figure 2 To the left the flap design with voids in the chordwise direction and 2) flap design with voids in the spanwise direction.

The development work from 2011 to 2014

After the prove of the concept by the wind tunnel testing in 2009 the development work has , as mentioned above, continued within the INDUFLAP project with focus on transferring the flap technology to industry as concerns manufacturing and testing. Basically the work has been within four main areas:

- 1) Flap design, materials and manufacturing techniques
 - a. The industrial partner Rehau has worked with manufacturing flaps with voids in spanwise direction in an extrusion process
 - b. The industrial partner Dansk Gummi Industry has carried out mold manufacturing of flap designs with chordwise voids
 - c. DTU has worked with mold manufacturing techniques of both flap designs (chordwise and spanwise voids)
- 2) Powering (pressurizing of voids) and control of flaps
 - a. These activities have been carried out by the industrial partner Hydratech and DTU
- 3) Investigation of lightning protection
 - a. DTU Electrical Engineering carries out modelling of impact of lightning as well as conducting lightning test on material samples as well as on a wing section with the flap system
- 4) Testing of flaps on an outdoor test rig
 - a. DTU has the responsibility of developing the rotating test rig and Hydratech contributes with input on the powering system of the flap and the control system

Flap design and manufacturing at Rehau

The detailed design of the flaps was mainly done by the use of the COMSOL software [5] simulating the complex stress distribution in the flaps with voids [6]. As an example is shown a case in Figure 3 where the geometry of the voids and the wall thickness were optimized to achieve a more uniform stress level on the surface of the flaps.

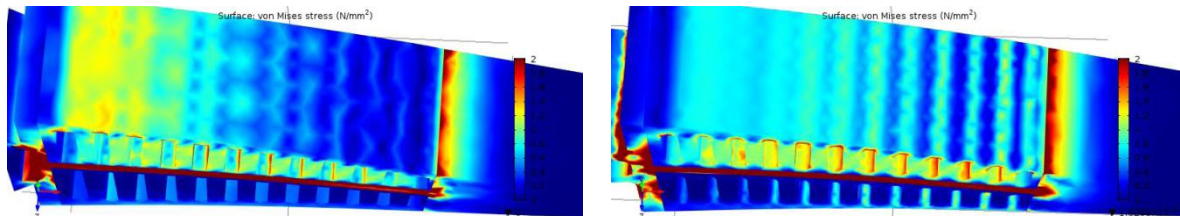


Figure 3 Computed stress contour levels on the flap with baseline void geometry to the left and another design to the right. The latter design was optimized with respect to achieve a more uniform stress level on the surface.

The industrial production of prototypes has been performed at REHAU in a multi component system that comprises an enforcement structure and two elastic active elements regulated in deformation by a pressurized fluid medium, left part of Figure 4. Fabrication of the active elements was performed by a continuous thermoplastic extrusion process in form of a quasi endless 12 chamber hollow profile. For manufacturing the sealed ends of the hollow profiles, a special method of a contact welding process has been developed, right photo in Figure 4.



Figure 4 To the left is shown the components of the flap before gluing the parts together. To the right the contact welding of the end caps is carried out.

Integration of the flap system on the blade

One of the advantages with the flap system is that the main blade is designed and manufactured without the normal trailing edge. Instead it is proposed that a web in the blade is inserted around 10-15% chord length from the trailing edge and the flap is easily connected to the blade with a two part connector as shown in Figure 4. In the present case for the first prototype the connector system has been manufactured in aluminum but in the final design it will be made in polymer material.

A blade design without the sharp trailing edge part and instead with the small trailing edge web is expected to be structurally preferable and to allow for considerable savings in finishing the blade trailing edge, as no finish work after inserting and gluing the web would be necessary. Furthermore, design studies indicate that the flaps could be mounted on the whole blade span from 50% radius and to the tip or started even closer to the root so that a blade with flat back airfoils on the inner part

could continue directly into the part where the flaps are mounted. Part of the flaps could be passive and mounting of the flaps could be carried out at the installation site and in sections of 2-3m.

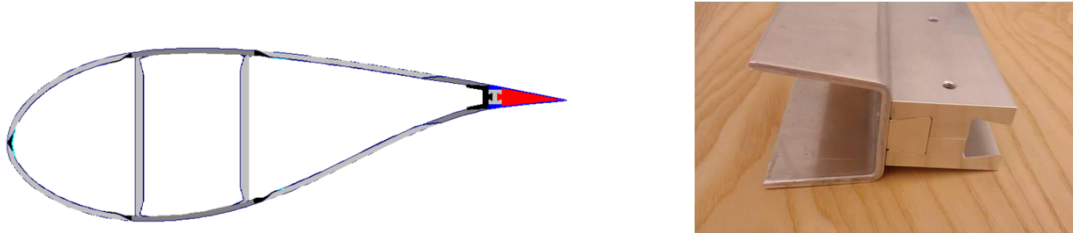


Figure 5 To the left is shown a sketch of the principle of mounting the flap onto the blade. To the right is shown the two part connector mounted on the left side on the web in the blade.

Flap powering for activation

In the design of the actuating system, great focus has been on efficiency, reliability and an environmentally friendly solution. Several different solutions were discussed, but especially the environmental focus turned the design towards a pneumatic solution, which would not have any environmental issues with leakage. The initial design was made with standard on/off valves to increase efficiency and reliability. The setup with these simple valves was able to yield seven different deflections of the flaps. Even though the input to the flap, with this solution, was by discrete steps, the actual output deflection turned out to be a satisfying continuous result. Therefore, a scaled system for the rotating test rig was designed to investigate the behavior in a rotating environment and with external loads.

Further studies on the actuating system are now turning the focus back to a solution with an incompressible fluid as the actuating media. Several advantages with a new fluid solution can be found, and different solutions are therefore being investigated, and will also be tested on the rotating test rig for comparison with the pneumatic solution. One advantage with the fluid solution is that the number of actuators will be limited to maximum two actuators per flap or perhaps as low as two actuators per blade depending on the control strategy. It will also be possible to remove the actuators from the blade and into the hub. This will of course be an advantage, as the ease of service would increase significantly. Furthermore, the stiff fluid system will decrease the response time, which aero elastic simulation [7] have shown to have great influence on the efficiency of the complete system. For the fluid system to be a success, it is very important that it is completely leak proof, as even a small leakage in the blade area will cause significant pollution of the surrounding environment.

Investigation of lightning protection

Wind turbine blades are expected to be struck by lightning several times during their life time. The flap system, as part of the blade, will be equally affected by direct and indirect effects of lightning discharges. The assessment of the effects of lightning on the flap system comprises the study of the lightning attachment on the blade, the lightning current distribution in a blade struck by lightning and

the electrical stress on the flap insulating materials due to the high electric fields caused by lightning.

The risk of lightning attachment on the flap surface is assessed by studying the origin and the propagation of streamers from different conductive elements of the blade, when exposed to a high electric field. The discharge formation has been investigated in small-scale models reproducing the blade. Calculations of the electric field in magnitude and direction have been performed with the finite element method and the results have been correlated with high voltage tests in the laboratory, as can be seen in Figure 6. The algorithms developed are an improved tool for the design of the blade and flap lightning protection, in particular to assess the effectiveness of the air termination system and the effects of internal conductive materials [8], [9].

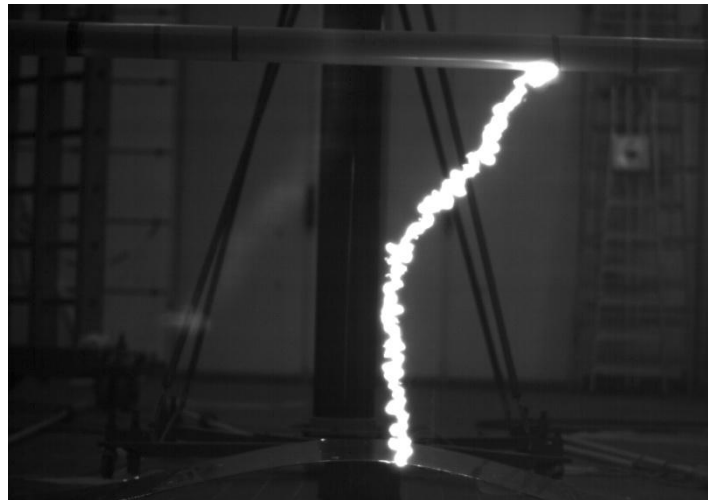


Figure 6 High voltage test reproducing a lightning discharge in the blade surface equipped with a grounded receptor.

The transient behavior of the lightning surges in the blade has been investigated with simulation models based on electric equivalent circuits. The results of the simulations show how the current is distributed in the conductive components of the blade and point at the areas where induced overvoltages may cause internal arcing [10].

The erosion and degradation of the blade rubber materials due to the lightning discharges has been determined by performing breakdown and tracking resistance tests. Breakdown strength tests were applied to a sample of the rubber material used in the flap structure as can be seen in **Error! Reference source not found.**, left. Figure 7, right shows how tracking resistance tests were applied to a set of samples of the rubber material used in the flap structure.

The study was focused on the relationship between the dielectric strength and the thickness of the samples, as well as the influence of interfaces between different layers of material. The results of the tests show that the flap material has properties comparable to the fiberglass material used in blades, regarding the interaction with lightning [11], [12].

The future work comprises high voltage attachment tests to a prototype of the flap system to validate the efficiency of the lightning protection designed for the flap system in intercepting the lightning discharge.

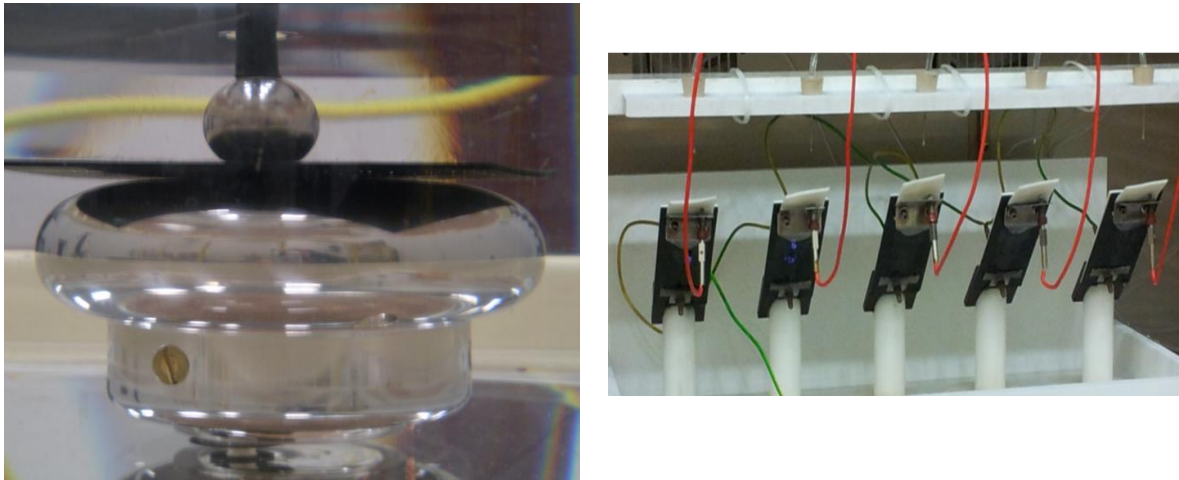


Figure 7 Test setups for determination of the blade rubber materials performance under lightning discharges. Left: Breakdown test setup, Right Tracking resistance test setup

Testing of flaps on an outdoor test rig

Testing the performance and robustness of the smart blade technology is an important part of the INDUFLAP project. Wind tunnel testing of the present flap system was done back in 2009 and proved that the actuation concept works in a wind tunnel. However, there is big step from wind tunnel testing on a stationary blade section to full scale turbine application and therefore a so-called rotating test rig has been developed in the INDUFLAP project.

The idea behind the test rig is that the testing should be as close as possible to the rotating test environment on the real turbine and have the same unsteady inflow conditions and a size of the flap not that far from full scale. This has been obtained by manufacturing a blade section with a 1m chord and 2m span and mounting it on a 10m long boom as shown below in Figure 8 and

Figure 9. The basic platform for the rotating test rig is the 100kW Tellus turbine positioned at the old turbine test site at DTU, Campus Risoe. The original three bladed rotor has been taken down as shown in

Figure 9 and a new full variable speed drive has been installed so the rotational speed with the boom mounted is controllable between 0 and 60 rpm.

A comprehensive instrumentation of the test rig has been carried out and includes sensors for the blade surface pressure distribution on the mid span position, which enable a continuous monitoring of the instantaneous sectional aerodynamic loading on blade, and thus also allow measuring the exact response of flap actuation. Another part of the instrumentation comprises two five hole pitot tubes of the leading edge of the blade section for measuring the inflow to the blade.

Finally, metrological data such as wind speed and wind direction is measured in three heights in a nearby met. mast.

In order to test different control algorithms that would be realistic on a full scale turbine the boom and the blade section can also be pitched. This will be used to test different strategies of combining pitch and flap control.

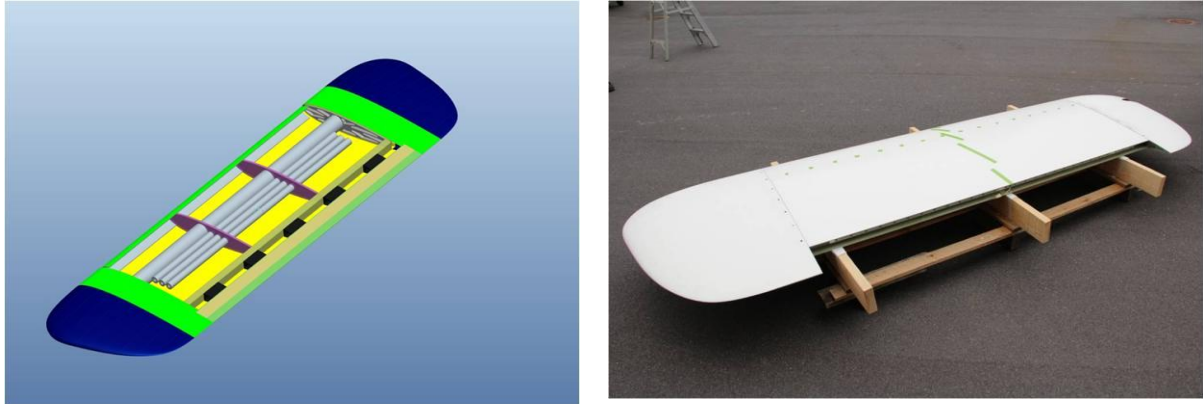


Figure 8 The flaps will be tested on a 2m long blade section with a chord of 1m. To the left is shown a CAD drawing of the blade section with the 15% flap mounted. To the right the manufactured blade section ready for instrumentation and for mounting the flap.

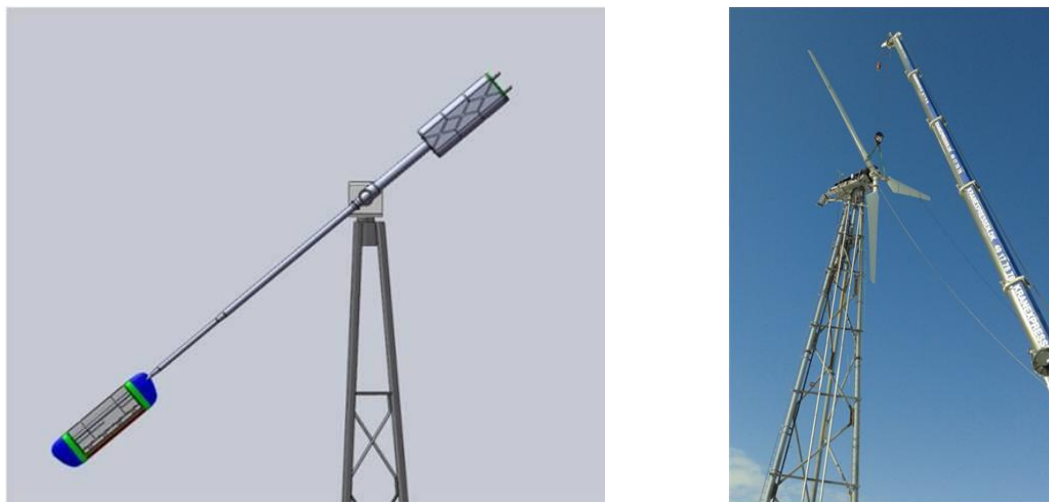


Figure 9 To the left is shown the principal layout of the rotating test rig. To the right is shown the 100 kW Tellus turbine at DTU, Campus Risoe which will be used as the basic platform for the rotating test rig.

Outlook

The rotating test rig is planned to be operational in April 2014 and then testing will continue over the summer. One of the aims is to measure the aerodynamic response characteristics of the flap system such as change in lift as function of flap angle and angle of attack (AOA) to the blade section. Also the dynamic response characteristics of the flap system will be an important

parameter to extract from the experiments. The measured data for the flap system will be used as input to an aeroelastic simulation model and enable to compute the load alleviation potential of the flap system mounted on a MW turbine.

Finally, it is expected that the testing of the flap system in the rotating test rig and the lightning tests will form the basis for a next step which could be testing on a full scale turbine, e.g. by implementing the system on an existing rotor.

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